EV351301011US

APPARATUS AND METHOD FOR TEMPERATURE CONTROL OF INTEGRATED CIRCUITS

Inventors:

Peter R. Wood; Narc V. Peralta; Frank S. Madren; and Dileep Sivasankaran

RELATED APPLICATIONS

The present application claims the benefit of U.S. provisional patent application number 60/418,897, filed October 15, 2002, entitled "System and method for operation of ethernet LAN products at extended high and low temperatures for temperature-uncontrolled outdoor applications," by Peter R. Wood; Narc V. Peralta; Frank S. Madren; and Dileep Sivasankaran, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to electronic systems. More particularly, the present invention relates to controlling the operating temperature of electronic components.

Description of the Background Art

As device sizes continue to shrink into the submicron region, packing densities have increased dramatically. One consequence of this heightened density is that the thermal energy generated by the operation of semiconducting devices is a significant factor that must be considered in designing an integrated circuit. Absent some form of heat management, heat from device operation would accumulate and degrade device performance or result in device failure. For example, conventionally, in order to prevent breakage and operational failure of a central processing unit (CPU), the CPU is typically cooled using a forced-air cooling fan and a heat sink.

While such cooling and heat dissipation mechanisms are important for typical applications of integrated circuits, they are insufficient for certain applications where cooling and heat dissipation alone cannot provide proper temperature control.

SUMMARY

One embodiment of the invention pertains to a method using both heat generation and heat dissipation for temperature control of an integrated circuit on a circuit board. A package containing the integrated circuit is heated using a heating element thermally coupled to the package. In addition, heat is dissipated from the package using a heat sink also thermally coupled to the package.

Another embodiment of the invention pertains to an apparatus for temperature control of an integrated circuit on a circuit board. The apparatus includes a first resistor on the circuit board, a second resistor on the circuit board, and a heat conductive material. The heat conductive material is attached to both the first and second resistors and to asurface of a package containing the integrated circuit.

Another embodiment of the invention pertains to a method for temperature control of an integrated circuit on a circuit board. An electrical current flowing through one or more resistive element is controlled so as to control generation of heat therefrom. The generated heat is conducted by way of a heat conductive element from the resistive element(s) to a surface of a package containing the integrated circuit.

Another embodiment of the invention pertains to an apparatus including a heater element, a temperature sensor, and a controller. The heater element and the temperature sensor are both thermally coupled to a surface of the body containing the integrated circuit. The controller is configured to receive temperature data from the temperature sensor and to use the temperature data to control heat generation by the heater element.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a layout for an apparatus for temperature control of an integrated circuit on a circuit board in accordance with an embodiment of the invention.

FIG. 2 depicts an elevation view of an apparatus for temperature control of an integrated circuit on a circuit board in accordance with an embodiment of the invention.

FIG. 3 depicts a circuit schematic for an apparatus for temperature control of an integrated circuit on a circuit board in accordance with an embodiment of the invention.

FIG. 4 depicts an elevation view of an apparatus for temperature control of an integrated circuit on a circuit board in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

As discussed above, conventional techniques are typically focused on cooling integrated circuits (ICs) to avoid overheating. However, in some operational environments, the conventional techniques are inadequate to maintain an IC within its operational limits.

Typical commercial ICs have a normal range of operation of roughly from zero degrees to seventy degrees Celsius, or thereabouts. Embodiments of the present invention may be utilized to effectively extend the operating temperature ranges of commercial or industrial ICs. For example, embodiments of the present invention may be applied to a commercial IC of an Ethernet hub or other device in a temperature-uncontrolled environment, such as the top of a cell tower, in an outdoor cable hub, on a telephone booth, in an

underground mine, in a factory, or other such environment. Specific applications include implementing outdoor IEEE 802.11 access points, outdoor video surveillance, outdoor communications using power line based technologies, space communications, and so on.

Embodiments of the present invention are designed to control the temperature of ICs in various operational environments. For example, if the operating temperature of an IC drops too low, performance of the IC slows or the IC may fail. Similarly, if the operating temperature of an IC goes too high, error or failure may occur. One aspect of the present invention relates to an apparatus that provides both cooling and heating functionality in order to maintain the operational temperature of the IC within an acceptable range.

FIG. 1 depicts a layout (plan view) for an apparatus for temperature control of an integrated circuit (IC) **102** on a circuit board in accordance with an embodiment of the invention. The IC **102** may comprise a CPU, a network processor, a microcontroller, or other integrated circuit device. The IC itself is contained in a package. The package is coupled to the circuit board by way of a socket or other appropriate connector. For example, the package may comprise a dual in-line package, a pin grid array, a ball grid array, or other package type.

In accordance with this embodiment, one or more resistor or resistive element is attached to the circuit board in proximity to the packaged IC **102**. In the particular configuration illustrated, the resistors or resistive elements R5 **104** and R6 **106** are placed on opposite sides of the packaged IC **102**. Also indicated in the layout are a temperature controller component U1 **108** and a transistor component Q1 **109**. The interconnections and operations between these various components are described further below. Also depicted are a couple of mounting holes **110** for attaching an optional part to the assembly to enclose the area for efficiency.

FIG. 2 depicts an elevation view of an apparatus for temperature control of an integrated circuit **102** on a circuit board **202** in accordance with an embodiment of the invention. A socket or other connector **204** is mounted on the circuit board **202**. The connector **204** is used to couple the packaged IC **102** to the circuit board **202**. Cross-sections of the two resistors **104** and **106** are shown. In this implementation, the resistors **104** and **106** are located on

opposite sides of the IC **102**. A heat conductive material **206** is attached to both the first **104** and second **106** resistors and to a top surface of the packaged IC **102**. The heat conductive material **206** may comprise a metal ribbon, such as a copper ribbon or an aluminum ribbon. The metal ribbon may be wrapped around each of the first **104** and second **106** resistors as shown. This wrapping is advantageous in promoting efficient heat transfer from the resistors and enables inexpensive resistors to be utilized as heating elements. The metal ribbon may be attached to the top surface of the packaged IC **102** using, for example, a thermal adhesive.

In another embodiment, the heat conductive material **206** may couple to the IC **102** by way of a different surface other than the top surface. For example, the heat conductive material **206** may be configured such that it transfers heat from a bottom surface of the IC **102**. For example, with a Dual In-line Pin (DIP) packaged chip, the heat conductive material **206** may be routed between the DIP and the circuit board. As another example, the heat conductive material **206** may be configured to transfer heat from the side surfaces of the IC **102**.

FIG. 3 depicts a circuit schematic for an apparatus for temperature control of an integrated circuit on a circuit board in accordance with an embodiment of the invention. The circuitry includes components depicted in FIG. 1, such as the first R5 **104** and second R6 **106** resistors, the controller U1 **108**, and the transistor Q1 **109**. Other components are also included.

The controller U1 **108** may be implemented, for example, using a thermostat control device such as the LM 56 Dual Output Low Power Thermostat available from National Semiconductor Corporation. The LM 56 includes eight pins. VREF (pin 1) is a voltage reference output pin. GND (pin 4) is electrical ground pin, and VCC is the positive voltage supply pin (pin 8). VT2 (pin 2) is an input pin for the low temperature trip point voltage for OUT2 (pin 6), and VT1 (pin 3) is an input pin for the temperature trip point voltage for OUT1 (pin 7). VTEMP (pin 5) is the temperature sensor output pin. OUT1 and OUT2 are open collector digital outputs. OUT1 is active low and goes low when the temperature is greater than a temperature T1 set by VT1 and goes high when the temperature drops below T1 minus 5 degrees Celsius. OUT2 is active low and goes low

when the temperature is greater than a temperature T2 set by VT2 and goes high when the temperature is less than T2 minus 5 degrees Celsius. The values of the resistors R1, R2, and R3 are selected to set T1 and T2 to the desired temperature levels. The LM56 includes an internal temperature sensor.

In this application of the LM56, OUT1 is used to control the transistor Q1 **109**. When the temperature sensed drops below about T1 minus 5 degrees Celsius, OUT1 goes high and so "turns on" the transistor Q1 **109**. In this state, electrical current flows from VCC, through the resistors R5 **104** and R6 **106**, through Q1 **109**, to ground. With electrical current flowing through the resistors R5 **104** and R6 **106**, heat is generated therefrom. The heat is conducted by the heat conductive material **206** from the resistors R5 **104** and R6 **106** to the top of the IC package **102**. When the temperature of the IC **102** increases such that the temperature sensed goes above T1, then OUT1 goes low and so "turns off" the transistor Q1 **109**. In this state, electrical current stops flowing through the resistors R5 **104** and R6 **106**, and so the heat generation stops.

Note that much of the temperature sensed by the internal sensor is due to the temperature at the leads (pins). Hence, the LM56 should be configured such that the temperature at the leads of the LM56 is close to, or reflects changes in, the temperature of the IC **102**.

A different embodiment may be based on a different thermostat controller device **108**. An external sensor that is more closely coupled thermally to the IC **102** may also be utilized.

FIG. 4 depicts an elevation view of an apparatus for temperature control of an integrated circuit **404** on a circuit board **402** in accordance with another embodiment of the invention. Here, the IC body **404** is shown mounted on the board **402**. A heat spreader **406** is attached to the top of the IC body **402**, and an insulating substrate **408** is attached to the top of the heat spreader **406**. Attached to the top of the insulating substrate **408** is a heat sink **410**. The heat sink **410** is thermally coupled to the heat spreader **406** by way of thermal vias or passageways **409** through the insulating substrate **408** and is used for efficient dissipation of heat therefrom. These thermal vias **409** are filled with a conductive material, such as aluminum or another metal.

In this embodiment, the heat spreader **406** is configured such that there is a cavity therein facing the insulating substrate **408**. The cavity is separated from the IC body **404** by a relatively thinner portion of the heat spreader **406**. Within an inner portion of the cavity, attached to the insulating substrate is a heater element **412**. Also within the inner portion, closer to the heat spreader **406**, is a temperature sensor and associated controller **416**. Two external wires, power and ground, may be coupled to these devices within the cavity to enable their operation. An optional third external wire may be coupled to the controller for purposes of remote control of the heater (or for programming memory associated with the controller). The controller is configured with circuitry to receive temperature data from the temperature sensor and to use the temperature data to control heat generation from the heater element **412**. A thermal gel filler **414** may be used to fill the remaining space in the inner portion and may be confined to the inner portion. The thermal gel filler **414** thermally couples the heater element **412** and the temperature sensor to the IC body **402**. An outer portion of the cavity may comprise an air gap **418** that provides some thermal separation.

The heater element **412** is attached to a bottom surface of the insulating substrate **408** at a location so as to be separated from the thermal vias **409**. This is advantageous in that more of the heat generated by the heating element **412** is conducted by the thin portion of the heater spreader **406** to the IC body **404** and less of the heat generated is conducted by the thermal vias **409** to the heat sink **410**. In other words, this configuration provides at least partial thermal separation of the heater element **412** from the heat sink **410** by the insulating substrate **408** such that heat generated by the heating element **412** is primarily directed towards the IC body **404** and not towards the heat sink **410**.

In accordance with another embodiment of the invention, programmable memory (for example, flash memory, EPROM, EAPROM, or other form of programmable memory) may be included with the controller. The programmable memory may be programmed so as to provide for customized control characteristics that depend on the specific application. For example, the memory may be programmed to hold information about the boundary temperatures to be used by the temperature controller. With such

programmable memory included, customization of the packages may be performed even after product assembly if the package includes a programming interface.

In accordance with another embodiment, the controller device may be configured to provide initial heating of an IC during a cold start of a system. In other words, the controller would be configured such that heat is generated to warm up a system prior to power being applied to the IC. In certain circumstances, such warming up of the IC may be used to evaporate moisture that may have condensed thereon.

In accordance with another embodiment, the IC may be encapsulated with a sealed environment. Such an embodiment may be useful in a corrosive atmosphere, for example, one in which hydrogen sulfide gas is present as in a copper mine. Encapsulation may also be advantageous in high altitude airplane or space applications.

Embodiments of the present invention are suitable to control the temperature of integrated circuits in various unfriendly environments. Otherwise, if the temperature drops too low, performance of the IC slows or the IC may fail. Typical commercial ICs have a normal range of operation of roughly from 0 degrees to 70 degrees Celsius, or thereabouts. Embodiments of the present invention may be utilized to extend the temperature range of environments in which commercial or industrial ICs operate. For example, the above-described embodiments may be applied to a commercial IC of an Ethernet hub or other device in a temperature-uncontrolled environment, such as the top of a cell tower, in an outdoor cable hub, on a telephone booth, in an underground mine, in a factory, or other harsh environment. Specific applications include implementing outdoor IEEE 802.11 access points, outdoor video surveillance, outdoor communications using power line based technologies, space communications, and so on.

In the above description, numerous specific details are given to provide a thorough understanding of embodiments of the invention. However, the above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. One skilled in the relevant art will recognize that the invention can be practiced

without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring aspects of the invention. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of the invention is to be determined by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.